Hydraulic Pulldown Procedure for Collecting Large Soil Monoliths

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ABSTRACT

SOIL monoliths 3-m (9.8-ft) square and 2.4-m (7.8-ft) deep were collected by hydraulically jacking bottomless steel boxes into a clay loam soil. Four jacking assemblies that utilized commercially availabe 178-kN (40,000-lb) hydraulic jacks were anchored to bell-bottomed piers at the corners of the steel boxes. A pulldown frame supported the jacking assemblies over the piers and uniformly distributed the pulldown force over the 9.5-mm (3/8-in.) thick walls of the steel boxes. Soil around the walls of the steel boxes was excavated as the boxes were jacked down. The procedure is a major advance in the collection of large soil monoliths. Bell-bottomed piers or similar anchors provide larger pulldown forces than are practical with deadweights, and hydraulic jacks or cylinders offer precise control of the downward movement. The technique is economically feasible for large soil monoliths, especially where the pulldown equipment can be reused to collect several monoliths.

INTRODUCTION

Many soil, crop, and hydrologic studies require large, undisturbed masses of soil that are called soil monoliths. For example, the ideal lysimeter for studying evapotranspiration should contain an undisturbed, representative soil profile. Most large lysimeters, however, have backfilled soil tanks because of the difficulty and expense of collecting large soil monoliths.

Soil monoliths for lysimeters are usually obtained by pressing bottomless steel boxes or cylinders into the soil. The soil on the outside may or may not be removed as the monolith container is forced down. The large monoliths at Coshocton, OH, were collected by weighting bottomless, rectangular, concrete boxes with sand bags and hand excavating around the outside of the walls (Harrold and Dreibelbis, 1951). Tackett et al. (1965) used 15.5 Mg (34,100 lb) of static mass to force 0.8-m (2.6-ft) diameter cylinders 1.8 m (5.9 ft) into a clay loam soil. Doering (1963) described the encasement of 0.46-m (1.5-ft) square by 0.61-m (2-ft) deep soil monoliths by first trenching around the core and then forcing a square box of 3-mm (0.125-in.) steel plates over the core. Brown et al. (1974) used two backhoes to force steel boxes as large as 1.5 m by 2.0 m by 1.5 m deep (5 ft x 6.7 ft x 5 ft) into the soil. They had to trim the monolith to nearly the internal dimensions of the box before it could be pressed to full depth. More recently, Dugas et al. (1985) used deadweights totaling 12 Mg (26,400 lb) and a slight rocking motion with a backhoe to collect a 1.5-m by 2.0-m by 2.5-m deep (4.9-ft x 6.6-ft x 8.3-ft) monolith. Circular monoliths as large as 3.0 m (10 ft) diameter by 1.2 m (4 ft) deep have been collected with a large caisson drilling rig (Armijo et al., 1972).

Documented procedures for collecting large soil monoliths have three major limitations. The force available to press monolith containers into the soil has been limited, controlling the rate of downward penetration of weighted boxes is very difficult, and maintaining the wall of the boxes in a plumb line is also very difficult. Because of the limitations of deadweights, backhoes, and drilling rigs, an alternate procedure is desirable for pressing large monolith containers into the ground.

This paper presents a procedure for installing bell-bottomed piers as earth anchors and pulling the monolith containers into the soil with hydraulic jacks. The procedure is a refinement and major scale-up of the one used by Belford (1979) and Meyer et al. (1985) to collect cores less than 1 m (3.28 ft) in diameter. Monoliths were collected in Pullman clay loam soil (fine, mixed, thermic Torrertic Paleustoll) at the USDA Conservation and Production Research Laboratory, Bushland, TX. The Pullman subsoil limits water movement and plant rooting, and studies have shown major differences in plant growth on modified soil profiles (Eck and Taylor, 1969; Schneider and Mathers, 1970). Thus, monolith soil cores are required for accurate evapotranspiration measurements and to exactly duplicate field hydraulic conditions.

INSTALLATION TECHNIQUE

Figs. 1 and 2 illustrate the overall technique for jacking the 3-m (9.8-ft) square by 2.4-m (8-ft) deep monolith containers into the soil. To obtain the pulldown force, we installed a bell-bottomed pier outside each corner of the square container. We fabricated a pulldown frame that distributed the downward force over the container walls and extended over each of the piers.

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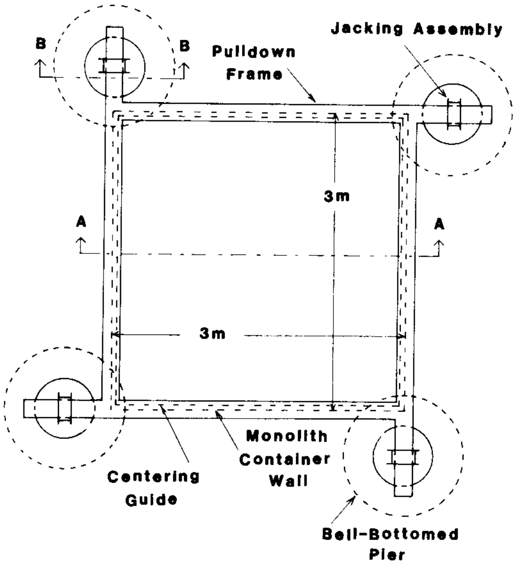

Fig. 1—Top view of monolith container and installation equipment.

We also designed and fabricated hydraulic jacking assemblies for connecting the frame to the piers and pulling down the steel containers (Fig. 3). We reinforced the walls of the steel container from the outside with S3 x 5.7* beams, so we excavated along the entire perimeter

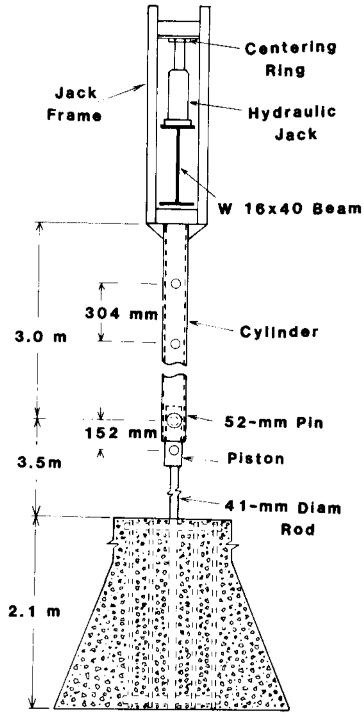

Fig. 3—Section (B-B in Fig. 1) of the jacking assembly connecting the pull-down frame and bell-bottomed piers.

of the container as we jacked it down. When the steel containers were jacked to the desired depth, we undercut them, lifted them from the excavated site, and overturned them to install a drainage system and a reinforced steel bottom. We then set the monoliths on mechanical scales and used them for monolithic weighing lysimeters.

*In American Society for Testing Materials notation, the letter denotes the beam shape, the first number denotes the beam depth in inches, and the second number denotes the beam weight in lb/ft.

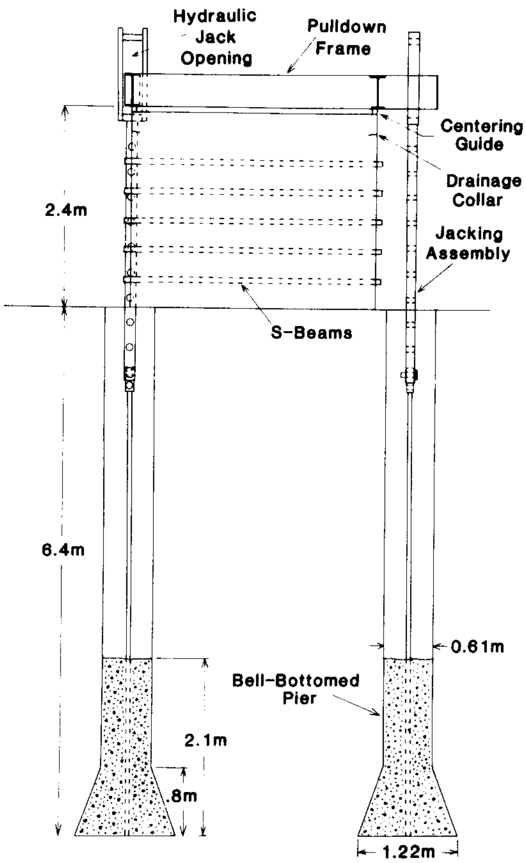

Fig. 2—Section (A-A in Fig. 1) of soil monolith container and hydraulic pull-down equipment.

EQUIPMENT DESIGN

Since adequate pulldown force is critical for the hydraulic pulldown procedure, we present details of the bell-bottomed pier design. The other main components are described, but without detailed computations.

Bell-Bottomed Piers

Soils in the Southern High Plains usually have high allowable soil bearing capacities, and bell-bottomed piers are the normal anchor for resisting uplift forces. For this reason, we selected deep drilled piers to develop the required pulldown force (Fig. 2). The sediments underlying most soils in the area are quite uniform, and soil test data were available from an area approximately 1 km (0.6 mi) east of the monolith site (Tillery, 1985).

Design of the bell-bottomed piers is complicated by the downward force exerted by the monolith container. If the downward force was continuous around the piers, they could be designed as tiebacks (McMahon, 1986). With only partial loading around the pier, a tieback design gives an overly high allowable loading. On the other hand, designing the piers as a foundation subject to a vertical uplift force gives a conservative design. We selected the conservative foundation design rather than a more complex analysis allowing for the downward force on the monolith.

We used the analysis of Bowles (1977) to calculate the ultimate uplift resistance of the piers. This resistance is the sum of cohesion of the soil, passive earth resistance, and weight of the soil and concrete cylinder. Using the terminology of Bowles (1977), the ultimate uplift resistance T_u is:

$$T_u = \pi cBH + S_f(\pi/2)\,\gamma\,B(2D-H)\,HK_u\tan\phi + W$$

where

c = cohesion of the soil, kPa
B = pier bell diameter, m
H = limiting pullout depth, m
S_f = dimensionless shape factor
γ = soil specific weight, N/m^3
D = depth of pier, m
K_u = passive earth resistance coefficient
ϕ = angle of internal friction, deg
W = weight of the concrete and soil within the bell diameter, N

The design values not listed on Fig. 2 are:

c = 14.4 kPa (300 lb/ft^2)
γ = 18.8 kN/m^3 (120 lb/ft^3)
ϕ = 25 deg
H = 3.67 m (12.0 ft)

Additional values given by Bowles (1977) are:

S_f = 1.30
K_u = 0.74

Substituting these values into the uplift resistance equation gives:

T_u = 496 kN (111,000 lb).

Since we were designing for 178 kN (40,000 lb), the safety factor was 2.8, which is satisfactory for foundation designs. The design is also conservative because we did not account for the downward force on the soil beneath the monolith container.

Soil Monolith Containers

The soil monolith containers were bottomless, square, steel boxes reinforced on the outside with S3 x 5.7 beams. The top edges of the 9.5-mm (3/8-in.) thick walls were square cut, and the bottom edges were cut at a 45 deg angle with the sharp edge to the inside. With reinforcing on the outside of the walls only, we could take a smooth-walled, continuous soil monolith to the desired depth of 2.4 m (7.8 ft). This soil depth allowed for 76 mm (3 in.) of freeboard above the soil surface.

Locating the S-beams along the walls gave the desired strength for a monolithic lysimeter container, but the absence of beams at the top and bottom was inefficient for the pulldown operation. When we applied force at the corners of the pulldown frame, the majority of the force was transferred to the corners of the square container. Each wall then became a statically indeterminate beam, with the beam mass concentrated in the center rather than the top and bottom. To prevent warping at the top of the walls we welded a tight-fitting internal centering guide of square tubing to the bottom of the pulldown frame (Fig. 2). To prevent warping at the bottom, we applied continuous horizontal force to the walls with hydraulic jacks during the pulldown operation.

Pulldown Frame

The main requirements for the pulldown frame were that it be sufficiently rigid and that it allow machine

Fig. 4—Excavating around a monolith container with a backhoe.

excavation around the monolith container (Fig. 4). To maintain deflection within tolerable limits, we selected W16 x 40 beams to cover the container walls and extend over the piers (Fig. 1). Use of a single beam rather than a built up section decreased the fabrication time. The centering guide around the bottom of the pulldown frame fit snugly inside the monolith container walls. The internal placement insured a snug fit because the centers of the walls were warped inward slightly after welding the drainage collar.

To allow soil excavation around the pulldown frame and monolith container, we used the configuration illustrated in Fig. 1. We could position a backhoe at each corner to excavate along an entire wall (Fig. 3). This kept hand excavation to the minimum that was required near the walls of the monolith container.

Jacking Assembly

The jacking assemblies consisted of hydraulic jacks, a jack frame, and a telescoping linkage between the pulldown frame and the bell-bottomed piers (Fig. 3). We estimated the maximum force for pulling down the monolith container from published shear values of clay loam soils and the total inside area of the container. The 178-kN (40,000-lb) jacks selected were the smallest commercially available size that equaled or exceeded this force. We then designed all other components to match the maximum force generated by the hydraulic jacks.

Selection of the hydraulic equipment was a trade-off between the lower cost of hydraulic jacks and the convenience of self-aligning pull-type hydraulic cylinders. We found that hydraulic cylinders cost approximately ten times as much as the jacks and selected standard 178-kN (40,000-lb) hand jacks. To prevent overturning of the jacks, we welded jack frames to 3.1-m (10.3-ft) long cylinders to obtain long, rigid assemblies. We also used centering rings to center the top of the pulldown assemblies over the hydraulic jacks. Since the lifting distance of a hydraulic jack is only 150 to 200 mm (6 to 8 in.), we needed a telescoping linkage between the jacks and the bell-bottomed piers.

The telescoping linkage we used was a single section of round tubing over a piston (Fig. 3). We fabricated the cylinders from 120-mm (4 3/4-in.) diameter by 9.5-mm (3/8-in.) wall thickness mechanical tubing and machined the pistons from 95-mm (3 3/4-in.) diameter cold rolled steel shaft. To reduce the number of 52-mm (2 1/16-in.) pin holes, we spaced the holes 304 mm (12 in.) apart in the cylinder and 152 mm (6 in.) apart in the piston. The pistons were welded to the 41-mm (1 5/8-in.) diameter structural steel rods that extended to the bottom of the concrete piers. The movable part of each jacking assembly could be raised or lowered with the hydraulic jack to align the pin holes in the piston and cylinder. Since the cylinder and jack frame had a combined mass of 125 kg (275 lb), this made the pin changes easy and fast.

INSTALLATION PROCEDURE

Several months before we jacked down the monolith containers, we wetted the soil profiles to reduce the strength of the undisturbed soil. The area had been dry farmed for 50 years or more, and the initial soil water content at the 1- to 3-m (3.3- to 9.8-ft) depth was only 0.16 to 0.20 m^3/m^3. We added sufficient water to raise the soil water content above 0.25 m^3/m^3 to the 3-m (9.8-ft) depth.

Pier Installation

A drilling contractor drilled the 0.61-m (2-ft) pier holes with a bucket auger drilling machine and belled the bottoms to a diameter twice that of the piers. We welded centering guides to the 41-mm (1 5/8-in.) diameter steel rods and tied the rebar cages to the centering guides. When we set the assembled pistons, rods, and rebar into the pier holes, we set all four pistons to the same elevation with surveying equipment. We then poured premixed concrete into the pier holes to the 4.3-m (14-ft) depth and vibrated it with a concrete vibrator.

Jacking Down the Soil Monolith Containers

We installed the monolith containers by alternately excavating around the bottom edge of the walls and then jacking down the containers. When we excavated around the container, we left 50 to 75 mm (2 to 3 in.) of soil outside each wall. This extra soil was sheared off by the sharp edge of the monolith container as it moved downward. Fig. 4 shows one of the containers jacked about halfway into the soil. Jacking the first monolith container into the soil took seven workers about 2 1/2 days. As the workers gained experience, installation time decreased; and nine workers jacked the fourth monolith container into the soil in one day.

The downward force on the monolith containers varied linearly with the depth of soil inside the containers, but other factors could have an influence. To measure the force, we installed pressure gauges scaled to read directly in force units on two of the four hydraulic jacks. At the 0.5-m (1.6-ft) depth, the total force was generally in the 108- to 179-kN (24,000- to 40,000-lb) range. When the containers had been jacked to the 2.3-m (7.8-ft) depth, the total force was generally in the 538- to 717-kN (120,000- to 160,000-lb) range. The main factors causing the force to vary were the speed of jacking down the container, the depth of excavation below the cutting edge, and the bottom S-beam pressing against unexcavated soil.

The main problem we encountered during installation of the monolith containers was bending of the walls at the bottom. During installation of the first monolith box, the walls had bowed out about 75 mm (3 in.) when the box was halfway into the ground. At that point, we positioned a horizontal hydraulic jack along the bottom center of each wall and continuously applied 44 to 88 kN (10,000 to 20,000 lb) of force against each wall. This prevented the bending from becoming more severe, but the enlarged monolith continued to move up the container as it was jacked down. On subsequent monolith containers, we started using the horizontal jacks as soon as the bottom edge of the container was below the soil surface. By using a bearing plate along the bottom of each 3-m (9.8-ft) wall to distribute the horizontal force, we restrained the bending to less than 25 mm (1 in.).

Undercutting and Overturning the Monoliths

After the monolith containers were jacked down, we undercut them, installed temporary tops on them, and then used two cranes to lift the monoliths out of the ground and turn them upside down. This procedure allowed us to install a suction drainage system and obtain higher quality welding on the bottoms and supporting beams. In addition, the retainer box and scales for the lysimeter could be installed concurrently at the site where we obtained the monolith.

To undercut the monolith boxes, we used a pneumatic boring tool normally used to install pipelines under roads and existing structures. With the boring tool manufactured by Vibra King† of Mankota, MN, we bored eight 76-mm (3-in.) holes and then expanded the bore holes to 105 mm (4.125 in.). The bore holes were uniformly spaced across the monolith container and about 150 mm (6 in.) below the bottom edge.

As the holes were bored, we installed 75-mm (3-in.) standard steel pipe inside the holes. To minimize the excavated work area for installing the pipes, we installed them in two sections and welded them together with a 0.76-m (2.5-ft) length of 64-mm (2 1/2-in.) heavy wall steel pipe, reinforcing the welded connection.

After the eight pipes were installed beneath a monolith container, we placed a W8 x 21 beam beneath each row of pipe ends (Fig. 5). These beams were temporarily connected to the container walls by welding several steel bars to both the beams and the walls. We then broke the monoliths from the soil below with the four 178-kN (40,000-lb) hydraulic jacks used to jack down the monolith containers.

The monoliths were then lifted out of the ground and overturned with two 222 kN (50,000-lb) cranes. Fig. 5 illustrates a monolith after the first of two quarter turns to place it upside down. At that point, weighing lysimeter equipment installation could proceed in a manner similar to that for a back-filled lysimeter (Howell et al., 1985). Marek et al. (1988) describe the design of the other weighing lysimeter equipment.

†Mention of a trade name or product does not constitute a recommendation or endorsement for use by the U.S. Department of Agricultural Experiment Station, nor does it imply registration under FIFRA as amended.

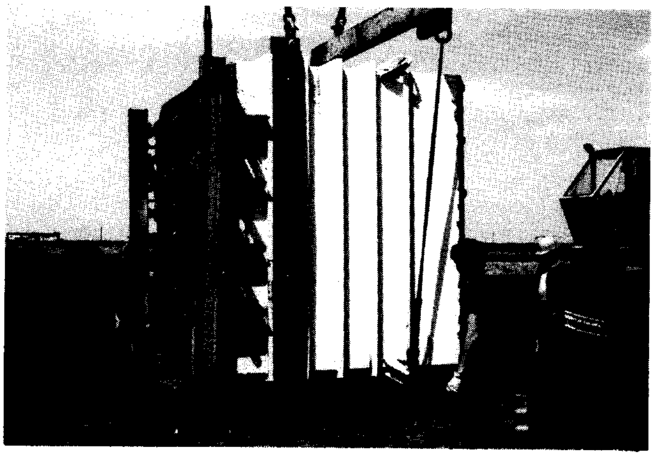

Fig. 5—View of a soil monolith container showing the shear plane of the soil and the pipes and beams used to hold the soil inside the container.

TABLE 1. COST OF MATERIAL AND SHOP LABOR FOR FABRICATING THE EQUIPMENT TO COLLECT THE SOIL MONOLITHS

Reusable equipment	
Jacking assemblies	
Materials and machine shop time	$ 1,880
Labor (9 days)	900
Pulldown frame	
Materials	800
Labor (6 days)	600
Hydraulic jacks (4)	500
Equipment for undercutting and overturning monoliths	
Soil boring tool	5,280
Materials (beams, pipe, plate, etc.)	2,240
Labor (8 days)	800
Reusable equipment total	$13,000
Nonreusable equipment	
Concrete anchors	
Materials and contract drilling	1,010
Labor (3 days)	300
Monolith box	
Materials	2,650
Labor (20 days)	2,000
Nonreusable equipment total	$ 5,960

DISCUSSION

The hydraulic pulldown procedure for collecting large soil monoliths has several advantages over earlier techniques. The main advantages are:

1. Large pulldown forces can be obtained with light equipment.
2. Control of downward movement and vertical alignment is excellent.
3. All equipment except the concrete piers can be reused.
4. Low cost with multiple use of the pulldown equipment.

The most serious problem we encountered was the warping of the monolith container walls along the bottom. Since the bottom of the container is a cutting edge, it cannot be reinforced. If the monolith is to be used as a lysimeter, the top of the box is best left unreinforced. In view of these limitations, maintaining the walls straight with horizontal hydraulic jacks appears more realistic than heavily reinforcing the box to prevent bending.

If the monolith boxes are to be lifted and overturned, a much more important design consideration is providing good connectors or hooks on the container. Since the top and bottom of the box are not enclosed, these edges do not have sufficient strength to support the weight of the box. To prevent damage, the box must be lifted up and overturned in the air.

Anchors other than bell-bottomed piers could also be considered for jacking down soil monolith containers. Bell-bottomed piers are well suited to soils that can easily be drilled and have large allowable soil bearing capacities. The most likely alternative would be the grout column, which is simply a straight bore hole with an anchor rod grouted into it. In rock formations, a working bond stress between the concrete and rock of 690 kPa (100 lb/in.^{2}) is reasonable (McMahon, 1986). The bore hole could be as small as 100 mm (4 in.) and only a few meters (feet) deep. In sand, working stresses of 48 kPa (1,000 lb/ft^2) are reasonable (Auld and Lodde, 1979). Bore holes for the anchors can be as much as 0.3 m (1 ft) in diameter and deep enough to develop the required working force. Because of the high cost and limited vertical capacity of back-filled anchors, they are usually not a viable alternative to piers or grout columns.

The costs of material and shop labor for fabricating the equipment to collect the soil monoliths are listed in Table 1. We fabricated this equipment in the laboratory machine and welding shop, and depreciation is not included for the existing shop and equipment. The jacking assemblies, pulldown frame, and hydraulic jacks that can be continually reused cost $4,680. Reusable equipment for undercutting and overturning the monoliths two at a time cost $8,320. For each monolith, the nonreusable concrete piers and steel box including welding on the bottom cost $5,960. Since we utilized the reusable equipment to collect four monoliths, the average cost per monolith was $9,210.

Collection of the monoliths required additional labor and equipment in the field. We utilized a backhoe, a front-end loader, and a flat-bed truck—equipment that is available at most field research laboratories. Time to collect the soil monoliths ranged from 18 man days on the first to 9 man days on the fourth. Undercutting a monolith and fitting the temporary top and other equipment required about 10 man days. Finally, lifting and overturning the monoliths in pairs required an average of $850 per monolith for crane rental.

The hydraulic pulldown procedure is a valuable new option for researchers who are collecting large soil monoliths. Developing large downward forces for pressing down a monolith box is no longer a limitation. Control of the downward movement is precise, regardless of the amount of force required. The pulldown equipment can be designed for circular, square, and rectangular monolith containers of varying sizes.

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